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Improving the renewable energy mix in a building toward the nearly zero energy status

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ABSTRACT

Developing Nearly Zero Energy Buildings (NyZEB) represents a path toward sustainable communities and is required by international regulations, starting with 2018. Combined measures for reducing the energy demand and increasing the share of renewable energy systems in buildings are very much investigated for different types of buildings. One specific case is represented by the buildings where – as result of the green energy policies – renewables are already installed, but the NyZEB status is not reached yet. These buildings are main candidates in getting this status as the initial investment required is significantly lower. A novel methodology is presented for this type of buildings aiming at identifying the optimal combination of actions to be taken for reducing the energy demand and developing optimized renewable energy mixes, integrating the existing ones, up to the (Ny)ZEB status. Following this methodology, a cases study is presented – the Solar House (low energy building with geothermal system and solar energy convertors) and the steps followed for reaching the Zero Energy Building standards are presented. Considering the current energy status of the building, the renewable energy potential and the costs, a tracked PV string array is proposed to be added and the steps in design optimization are outlined.

1. Introduction

The Energy Performance of Buildings Directive (EPBD) states that buildings account for 40% of total energy consumption in the European Union (EU) [1], and similar figures are valid for US (the 2010 value was 41% [2]) while a significant 25% is reported for China [3]. Many other studies are devoted to this aspect, resulting values of energy consumption in the building sector between 20% and 40%, exceeding the industrial and transportation sectors in developed countries [4]. About 10–20% from the energy consumption is embodied in the construction stage while 80–90% represents the energy use operating the building during the life cycle [5]. The energy demand during the lifetime of the existing buildings is expressed in terms of annual specific primary energy use which falls in the range of 150–400 kWh/m^2 per year for conventional residential buildings and 250–550 kWh/m^2 per year for office buildings [5], values that are very high considering the standards of 60–80 kWh/m^2 per year set for low energy buildings.

The energy consumption depends on the climatic conditions, users' behavior and on the building as such, consequently on the in force regulations when the building was constructed which imposed (or not) a minimum set of performance characteristics for the building materials. Considering the expected growth of population, up to 10 billion till 2050 [6], the expansion of the buildings sector is predictable, along with an increase in the energy consumption; therefore, for being sustainable, there is a need for solutions that will support a much lower rate in the energy increase as compared to the population growth.

The main requirements for the sustainable built environment, as described by the *Trias Energetica Concept*, are related to lowering the energy demand by combining energy saving, the efficient use of energy and waste minimization with increasing the share of renewable energy systems (RES) and using fossil fuels in the cleanest possible way, this also including emissions mitigation. Thus, the sustainable built environment cannot be developed without sustainable energy systems and these are intrinsically linked to spatial planning [7], in order to prevent unbalancing the resources and to avoid the competition with agriculture and forestry.

To speed up the process, legal instruments were launched, as it is the EPBD stating that by 31 December 2020, all new buildings should be Nearly Zero Energy Buildings, with implemented cost-effective solutions both in energy efficiency measures and in energy-supply systems including renewable energy sources [1]; as result plenty of work was devoted in the past five years for identifying adequate and customized solutions promoting low energy consumption and building integrated renewables [8–10], particularly focusing on the new buildings. This leaves the existent buildings as large energy consumers; being developed mostly in the '70s or before, these buildings are still functional but need (at least) refurbishing for lowering their energy need, therefore a

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special target is set through EPBD firstly for public buildings. This is important especially because new buildings only account for a very low percentage in the residential building stock (in EU 1.94% [11]).

Attempts for promoting energy efficiency in buildings were done but the pace is much slower than initially planned and the reasons are mainly related to the acceptance coming from the building owners, to the conservative building industry with a huge number of suppliers, builders, designers and developers with lack of horizontal integration [12], and finally to the costs issues, raised from both parts. Therefore, sustainable and affordable solutions are needed, making use of the available infrastructure and energy resources based on an integrated design. This is important because generally, through integrated design up to 90% reductions in the energy use can be achieved in the new low-energy buildings and more than 50% for the existing building renovation, almost everywhere in the world [13].

A specific category is represented by the buildings where different renewable energy systems were installed in the past years, as result of the support policies promoting sustainable energy. Being a direct (and fast) result of an opportunity, the systems in these buildings were separately designed and are separately operated, their mission being to reduce the consumption based on traditional (fossil) energy sources. As already having part of the required infrastructure, the conversion of these buildings toward the Nearly Zero Energy Building status involves lower investments and make them priority candidates for implementing the legal frame and for developing sustainable communities. To fully valorize the potential of these buildings, a specific integrated design is required, combining measures for reducing the energy demand and increasing the renewables.

This paper proposes for the first time (to the best of our knowledge) a design method mainly dedicated to these buildings, allowing cost-effective solutions. Following this method the path for reaching the Nearly Zero Energy Building (NyZEB) status is described based on in-field data, for The Solar House – a building that has implemented renewables and will be transformed in NyZEB.

2. Methodology

The methodology for reaching the NyZEB status in buildings with already installed RES follows three steps that are based on the evaluation of the existent energy status followed by step-wise measures for increasing the energy performance and extend the RES share up to the targeted level. The schematic description of the methodology is presented as a flowchart in Fig. 1.

Step I. Current energy status, aims at defining the input data as follows:

- Building characteristics considering the geometry, the envelope (materials, thermal and optical characteristics), the building type (household, office or industrial building), the inhabitants, etc. Additionally, spatial limitation for further implementing RES should be included (e.g. yet available roof, terrace or facades areas, with optimal orientation for solar energy convertors).
- Characteristics of the implementation site. These data are included in the calculation of the building energy demand and allows estimating the renewable energy potential. This can be done based on generated data using dedicated software, mainly relying on the geographical coordinates (latitude, longitude, height, clear sky index, etc.); using dedicated software has the advantage of minimal input information but can lead to under- or over-estimation of the renewable energy potential, with negative consequences on the final energy output and on the costs. Therefore, on-site data (collected at least over one year) are recommended for accurate RES design.
- Implemented RES, in terms of type ($RES_1 \ldots RES_k$, e.g. photovoltaic, wind, solar thermal systems, heat pumps, biomass, etc.) and energy output (average and extreme values); the total energy output of the renewable energy systems, RE, is calculated as the sum of the components ($RE = \Sigma RE_i$, with $i = 1 \ldots k$).
- Standardized indicators for renewable energy systems (initial investment cost, exploitation cost, payback time, cost/benefit ratio, CO_2 emission savings) and for Nearly Zero Energy Buildings.

The input data are used to calculate the energy demand (ED) of the building, using the building's characteristics, the weather data and the utilization type of the building. The energy demand considers the space heating and/or cooling load, the domestic hot water load and the power load for lighting. Elaborate or simplified engineering methods, statistical methods, neural networks, etc. are reported [14], and the major challenge is to correctly identify the models' input parameters in order to describe the building energy flow.

Based on the energy demand and on the share of renewables in the existing energy mix, the need for further implementing RES is evaluated. If the energy demand is fully satisfied by the already implemented RES the Zero Energy Building (ZEB) status is reached; if RE exceeds ED, the building has a Plus (Green) Energy status (PE) and, as also in the case of ZEB, no further measures are needed. It is to mention that the ZEB or the PE status can be reached during certain seasons in the year (most likely during summer) but the method hereby described proposes calculations covering one full year, as many other authors agree [15].

But, most of the existent buildings have the energy demand not fully covered by RES energy production. Two paths can be followed to meet the NyZEB status: decreasing the energy demand and/or increasing the share of RES.

Step II. Decreasing the energy demand. It is unanimously agreed that installing RES is output- and cost-effective in buildings where pervious energy efficiency and energy saving measures were implemented [16]. Thus, reducing ED is the next step by implementing the first and second stages of Kyoto Pyramid [17], by reducing the heat losses and by ensuring an efficient electricity use. In a practical approach, decreasing ED can be obtained by different measures that should be implemented according to the building's specifics: refurbishing the envelope, efficient lighting and equipment, even measures of passive solar design, if possible.

These combined measures can have a significant influence on the building performance, therefore a new assessment of the ED vs. RE is done. Similarly to Step I, if the ZEB or the PE status is reached, no further actions are required. If the measures for lowering the ED are not enough to meet the NyZEB status, Step III is further approached.

There might be situations when reducing the energy demand is no longer possible, as common and affordable solutions were already implemented. In these situations, the procedure further runs from Step I directly into Step III.

Involving the beneficiaries in the design process represents a key issue in increasing the acceptance of the sustainable energy solutions. Therefore, the method considers an inquiry step, when the users receive the quantification of the building performance with lowered ED and are asked if they further want to increase RE. As the NyZEB status is not strictly defined, the answer can be "No" (no need for further renewables), and in this case, no further action is taken. But, considering the legal frame and the conventional energy increasing costs, this option is likely to be less and less selected in the future, most of the users opting for an increase in the energy obtained based on renewables.